Status of claims and support for claim changes

10/820,561 **For Reissue of U.S. Pat. 6,373,868** February 10, 2010

1. Claims 1-15 are pending, except claim 10.

Applicant is advised by the Advisory Action to file an amendment with all the claims (1-15) and follow the guidelines of 37 CFR 1.173.

2. Current Amendment To Claim 10 without raising new issues

In claim 10 step 4: After "said end mirrors" adding "so as to promote single longitudinal mode operation".

It means that the sentence in claim 10 step 4 has been changed to

--- "creating said gain region within a narrow area along the optical axis of said cavity and immediately adjacent to one of said end mirrors so as to promote single longitudinal mode operation." ---

Now, there is the same pattern and term as that presented in claim 1 step 4.

3. Outline for Claims

In this reissue patent application there are two portions of the new set of the pending claims 1-15, i.e., claims 1-9 and claims 10-15, in order to replace the original set of claims 1-9 in Pat. 6,373,868. The pending claim 1 and claim 10 are the two independent claims.

The pending claims 1-9 are used to cover the situation with respect to a beam expanding laser cavity.

The pending claims 10-15 are used to cover the situation with respect to a regular laser cavity.

Each of them is very similar to the set of claims 1-9 in Pat. 6,373,868, in which only one independent claim covers these two situations.

In other words, the pending claims 1-9 have been kept almost the same as claims 1-9 in Pat. 6,373,868, except that the contents related to a regular laser cavity have been removed out and then become the pending claims 10-15.

The relevant more information has been presented in "Statement of Status/Support for all Changes to the Claims" filed on August 17, 2007.

4. The Amendment Paper by Markings

In this amendment paper all markings for the pending claims 1-9 are made in comparison to the original patent of Pat. 6,373,868. Considering the pending claims 10-15 was added to reissue patent application later, all markings for the pending claims 10-15 are made in comparison to those filed on July 17, 2006. So that these markings clearly show that the current pending claims 10-15 have been amended in response to the Office Actions dated August 29, 2008 and July 15, 2009, as well as the Advisory Action dated January 22, 2010.

5. Description for Claim 10

In the approach of claim 10 a formation of wavelength selectivity with low insertion losses is used in cooperation with a thin gain zone that leads to SLM operation. Therefore, the laser arrangement clearly consists of three limitations in claim 10:

(1) a laser gain region is very thin;

(2) the thin gain region is located adjacent to or in contact with an end laser cavity mirror; and

(3) a formation of wavelength selectivity with low insertion losses is placed within a laser cavity.

The function of the limitation (1) and (2) in the laser arrangement is to create a circumstance to promote SLM operation. In such a circumstance, all possible longitudinal modes have about an equal chance to extract the available gain. One lucky mode that begins to oscillate first wins the "mode-competition" and deprives the others of the gain needed to oscillate, thereby encouraging or enforcing single-longitudinal-mode (SLM) operation.

On the other hand, the effect caused by a thin gain region in contact with an end mirror is equivalent to that caused by short cavity configurations, in which those potential oscillating longitudinal modes are separated substantially. In such a case, the required resolving-power of a frequency-selective form will be largely relaxed and it becomes possible to use a formation with low insertion losses in realizing single-mode operation.

6. Reason for Patent

None of the searched prior arts alone or combination discloses the claimed method imitations presented in independent claim 1 or claim 10, respectively, having the combined recited steps for forming a laser cavity to obtain stable single longitudinal mode operation in order to solve the well-known so-called "green problem". In particular, nobody in the prior art has ever suggested and considered the use of a formation of wavelength selectivity with low insertion losses in cooperation with a thin gain zone, or the use of a spectral filter in cooperation with a beam expander to reduce the insertion losses, leading to stable single longitudinal mode operation.

[CLAIMS]

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This is the clean version of the entire set of the pending claims 1 -15 after the current amendment and will replace all prior versions, and listings, of claims in the application.

What is claimed is:

1. In a method for configuring a standing-wave cavity arrangement for solid-state lasers in obtaining stable single-mode operation, whereby overcoming the major difficulty with intracavity frequency conversions, typically in frequency doubling caused by the so-called "green problem", comprising the steps of
   (1) constructing a forming means for said cavity, including at least two end mirrors, wherein said cavity is a beam expanding laser cavity;
   (2) constructing a pump head means placed within said cavity for lasing at a fundamental wavelength; comprising the steps of
      A. selecting a solid-state laser medium means;
      B. selecting a pump source means including laser diode bars to provide relevant pumping beams for pumping said laser medium means; and
      C. producing a gain region within said laser medium means by said pump source means;
   (3) constructing a formation of wavelength selectivity with low insertion losses placed within said cavity, wherein the performance parameters of said formation are predetermined whereby to sufficiently and uniquely determine the laser's oscillating frequency and to force the laser to perform a stable single-mode or narrow band operation; and
   (4) selecting an approach for promoting single longitudinal mode operation from the group consisting of

A. a first approach, comprising

1) creating said gain region within a narrow area along the optical axis of said cavity and immediately adjacent to one of said end mirrors, and

2) selecting said formation from the group consisting of

a) a first formation, built up of a Lyot filter and a one-dimensional beam expander means, and

b) a second formation, built up of a spectral filter means including at least one spectral filter, and a two-dimensional beam expander means to reduce insertion losses for said spectral filter means substantially; and

B. a second approach, comprising

1) placing said pump head means between a pair of quarter-wave plates whereby producing the "twisted mode" operation, and

2) building said formation up of a spectral filter means consisting of at least one spectral filter, and a beam expander means to reduce insertion losses for said spectral filter means substantially.

2. In the method of claim 1, wherein said approach is said first approach, further comprising the steps of

(1) using a nonlinear crystal means arranged in an optimal condition including phase-matching for intracavity frequency conversion;

(2) maintaining the bandwidth of said formations to be smaller than the laser longitudinal oscillating mode interval of said cavity, and its free spectral range is larger than the FWHM of lasing bandwidth of the gain medium;

(3) selecting said spectral filter from the group including

A. Lyot filters, formed by a polarizing means and a birefringent element; and

B. etalons, including 1) regular etalons, and 2) birefringent etalons which acts likewise as an additional Lyot filter in conjunction with said polarizing means;

(4) selecting said polarizing means from the group including 1) Brewster plate, 2) Brewster surface, and 3) Brewster reflector;

(5) selecting said birefringent element from the group including 1) said nonlinear crystal means, and 2) said birefringent etalon;

(6) selecting said laser cavity from the group including 1) regular standing-wave cavities; 2) V-shaped standing-wave cavities; and 3) L-shaped standing-wave cavities;

(7) building said two-dimensional beam expander means up of an AR coated lens pair; which additionally comprises the steps of

A. placing an aperture means at the focal plane of said object lens where a diffraction-limited point occurs, so that said beam expander means is configured as a spatial filter likewise in conjunction with said aperture means, whereby leading to TEM.sub.00 mode operation and an output with an excellent spatial quality;

B. keeping a proper defocusing for said beam expander means whereby achieving compensation of the thermal lens effect leading to stable laser operations; and

C. locating said nonlinear crystal means adjacent to said aperture means or within the unexpanded beam portion.

3. In the method of claim 2, wherein said spectral filter means consists of at least one Lyot filter, in order to protect the laser polarization at the fundamental wavelength from being altered or affected by the amount of birefringence of

said nonlinear crystal means and said laser medium means; further comprising the steps of

(1)keeping said nonlinear crystal means to have a constant effective length to produce a phase retardation to be a half integral multiple of said fundamental wavelength, and

(2)selecting said laser medium from the group including1) nonbirefringent laser medium, 2) laser medium made and oriented without the exhibition of birefringences, and 3) birefringent laser medium having a constant effective length to produce a phase retardation to be a half integral multiple of said fundamental wavelength.

4. In the method of claim 2, further comprising the steps of

(1)maintaining a constant cavity length whereby stabilizing operation frequency;

(2)maintaining a constant temperature for said nonlinear crystal means whereby providing the best result for frequency conversion and minimizing cavity losses for the oscillating mode;

(3)constructing a wavelength tuning form for the alignment of said etalon transmission peak to said laser oscillation frequency; and

(4)constructing a defocusing control means for said two-dimensional beam expander means, wherein the degree of said defocusing is controlled by said control means for different pump and output power levels whereby obtaining good stability against thermal lens fluctuations.

5. In the method of claim 1, wherein said approach is said second approach, further comprising the steps of

(1) using a nonlinear crystal means arranged in an optimal condition including phase-matching for intracavity frequency conversion;

(2) maintaining the bandwidth of said spectral filter means is smaller than the laser longitudinal oscillating mode interval of said cavity, and its free spectral range is larger than the FWHM of lasing bandwidth of the gain medium, whereby to control the residual spatial hole burning;

(3) selecting said spectral filter from the group including

A. Lyot filters, formed by a polarizing means and a birefringent element; and

B. etalons, including 1) regular etalons, 2) said quarter-wave plate, and 3) birefringent etalons, in the later two cases said etalon acts likewise as an additional Lyot filter in conjunction with said polarizing means;

(4) selecting said polarizing means from the group including1) Brewster plate, 2) Brewster surface, and 3) Brewster reflector;

(5) selecting said birefringent element from the group including1) said nonlinear crystal means, 2) said pair of quarter-wave plates, and 3) said birefringent etalon;

(6) selecting said laser medium means from the group including1) nonbirefringent laser medium, 2) laser medium made and oriented without the exhibition of birefringences, and 3) birefringent laser medium having a constant effective length to produce a phase retardation to be a half integral multiple of said fundamental wavelength, whereby to protect said "twisted mode" operation from being degraded by the amount of birefringence of said laser medium means;

(7) selecting said laser cavity from the group including1) regular standing-wave cavities; 2) V-shaped standing-wave cavities; and 3) L-shaped standing-wave cavities;

(8) selecting said beam expander means to be a two-dimensional beam expander means built up of an AR coated lens pair; which additionally comprises the steps of

A. placing an aperture means at the focal plane of said object lens where a diffraction-limited point occurs, so that said beam expander means is configured as a spatial filter likewise in conjunction with said aperture means, whereby leading to TEM.sub.00 mode operation and an output with an excellent spatial quality;

B. keeping a proper defocusing for said beam expander means whereby achieving compensation of the thermal lens effect leading to stable laser operations; and

C. locating said nonlinear crystal means adjacent to said aperture means or within the unexpanded beam portion.

6. In the method of claim 5, further comprising the steps of

(1) keeping said nonlinear crystal means to have a constant effective length to produce a phase retardation to be a half integral multiple of said fundamental wavelength, whereby to protect the polarization and eigenvector of laser operation at the fundamental wavelength from being altered or affected by the amount of birefringence of said nonlinear crystal means;

(2) maintaining a constant cavity length whereby stabilizing operation frequency;

(3) maintaining a constant temperature for said nonlinear crystal means whereby providing the best result for frequency conversion and minimizing cavity losses for the oscillating mode;

(4) constructing a wavelength tuning form for the alignment of said etalon transmission peak to said laser oscillation frequency; and

(5) selecting a defocusing control means for said two-dimensional beam expander means, wherein the degree of said defocusing is controlled by said control means for different pump and output power levels whereby obtaining good stability against thermal lens fluctuations.

7. In the method of claim 1, wherein

(1) said approach is said second approach;

(2) said beam expander means is a prism beam expander which acts inherently as a polarizer likewise and is placed between said pump head means and said nonlinear crystal means, whereby 1) to reduce the insertion losses of intracavity optical elements, particularly for said etalon and said Lyot filter, and 2) to provide both large and small beam waists in one compact cavity, whereby to be able to achieve mode-matched pumping and efficient intracavity frequency conversion at the same time;

(3) said gain region is in the shape of a thin layer whereby accommodating the one-dimensional mode expanding;

and further comprising the steps of

(4) using a nonlinear crystal means located within the unexpanded beamportion and arranged in an optimal condition including phase-matching for intracavity frequency conversion,

(5) maintaining the bandwidth of said spectral filter means is smaller than the laser longitudinal oscillating mode interval, and its free spectral range is larger than the FWHM of lasing bandwidth of the gain medium, whereby to control the residual spatial hole burning;

(6) selecting said spectral filter from the group including

A. Lyot filters, formed by said prism beam expander and a birefringent element; and

B. etalons, including 1) regular etalons, 2) said quarter-wave plate, and 3) birefringent etalons, wherein in the later two cases said etalon acts likewise as an additional Lyot filter in conjunction with said prism beam expander;

(7) selecting said birefringent element from the group including1) said nonlinear crystal means, 2) said pair of quarter-wave plates, and 3) said birefringent etalon;

(8) selecting said laser medium means from the group including1) nonbirefringent laser medium, 2) laser medium made and oriented without the exhibition of birefringences, and 3) birefringent laser medium having a constant effective length to produce a phase retardation to be a half integral multiple of said fundamental wavelength, whereby to protect said "twisted mode" operation from being degraded by the amount of birefringence of said laser medium means.

8. In the method of claim 7, further comprising the steps of

(1) keeping said nonlinear crystal means to have a constant effective length to produce a phase retardation to be a half integral multiple of said fundamental wavelength, whereby to protect the polarization and eigenvector of laser operation at the fundamental wavelength from being altered or affected by the amount of birefringence of said nonlinear crystal means;

(2) selecting said laser cavity from the group including1) regular standing-wave cavities; 2) V-shaped standing-wave cavities; and 3) L-shaped standing-wave cavities;

(3) constructing a form for maintaining a constant cavity length for said cavity whereby stabilizing operation frequency, said form includes 1) selecting distance holders for said cavity forming means with a zero thermal expansion coefficient at room temperature, 2) selecting a temperature compensation cavity structure for said cavity forming means, and 3) selecting a temperature control means for maintaining a constant temperature for said cavity;

(4) constructing a temperature control means for said nonlinear crystal means to maintain a constant temperature in the optimal condition whereby providing the best result for frequency conversion and minimizing cavity losses for the oscillating mode; and

(5) constructing a wavelength tuning form for the alignment of said etalon transmission peak to said laser oscillation frequency; said tuning form includes 1) temperature tuning, and 2) angle tuning, in which the rotation axis of said etalon must be perpendicular to the plan expanded by said prism beam expander whereby reducing the etalon walk-off loss.

9. In the method of claim 1, further selecting a nonlinear crystal means arranged in an optimal condition including phase-matching for intracavity frequency conversion, wherein said frequency conversion includes

(1) second harmonic generation, wherein said nonlinear crystal including KTP;

(2) resonantly enhanced second harmonic generation, wherein

A. said nonlinear crystal means including KTP;

B. said formation is a regular etalon; and

C. said cavity arrangement is configured to resonate at said second harmonic frequency by a phase compensator means or cavity distance adjustor

means whereby largely enhancing the intensity of said second harmonic radiation and the conversion efficiency;

(3) third harmonic generation, wherein

said nonlinear crystal means is two nonlinear crystals positioned serially, in which the first crystal is set with type I phase-matching for doubling said fundamental radiation to produce the SHG, and the second crystal is set with type II phase-matching to mix said fundamental and second harmonic radiations so as to produce the THG;

(4) third harmonic generation with resonant harmonic generation, wherein

A. said nonlinear crystal means is two nonlinear crystals positioned serially, in which the first crystal is set with type I phase-matching for doubling said fundamental radiation to produce the SHG, and the second crystal is set with type II phase-matching to mix said fundamental and second harmonic radiations so as to produce the THG;
B. said formation is a regular etalon; and
C. said cavity arrangement is configured to resonate at said second harmonic frequency by a phase compensator means or cavity distance adjustor means whereby largely enhancing the intensity of said second harmonic radiation and the conversion efficiency;

(5) fourth harmonic generations, wherein

said nonlinear crystal means is three nonlinear crystals positioned serially, in which the first crystal is set with type I phase-matching for doubling said fundamental radiation to produce the SHG, the second crystal is set with type II phase-matching to mix said fundamental and second harmonic radiations for producing the THG, and the third crystal is set with type I

phase-matching to mix said fundamental and third harmonic radiations so as to produce the FHG;

(6) fourth harmonic generation with resonant harmonic generation, wherein

A. said nonlinear crystal means is two nonlinear crystals positioned serially, in which the first crystal is used for doubling said fundamental radiation to a second harmonic radiation, and the second crystal is for doubling said second harmonic radiation to a quadrupling harmonic radiation;

B. said formation is a regular etalon; and

C. said cavity arrangement is configured to resonate at said second harmonic frequency by a phase compensator means or cavity distance adjustor means whereby largely enhancing the intensity of said second harmonic radiation and the conversion efficiency;

(7) frequency mixing, wherein

A. further selecting an input radiation, including a resonantly enhanced input; and

B. said nonlinear crystal means mixes said fundamental and said input radiations to a mixing radiation; and

(8) frequency mixing with resonant harmonic generation, wherein

A. further selecting an input radiation;

B. said nonlinear crystal means is two nonlinear crystals positioned serially, in which the first crystal is used for doubling said fundamental radiation to produce the SHG, and the second crystal mixes said second harmonic and said input radiations to a mixing radiation;

C. said formation is a regular etalon; and

D. said cavity arrangement is configured to resonate at said second harmonic frequency by a phase compensator means or cavity distance adjustor

means whereby largely enhancing the intensity of said second harmonic radiation and the conversion efficiency.

10. In a method for configuring a standing-wave cavity arrangement for solid-state lasers in obtaining stable single-mode operation, whereby overcoming the major difficulty with intracavity frequency conversions, typically in frequency doubling caused by the so-called "green problem", comprising the steps of

(1) constructing a forming means for said cavity, including at least two end mirrors, wherein said cavity is a laser cavity without a beam expander;

(2) constructing a pump head means placed within said cavity for lasing at a fundamental wavelength; comprising the steps of

A. selecting a solid-state laser medium means;

B. selecting a pump source means including laser diode bars to provide relevant pumping beams for pumping said laser medium means; and

C. producing a gain region within said laser medium means by said pump source means;

(3) constructing a formation of wavelength selectivity with low insertion losses placed within said cavity, wherein the performance parameters of said formation are predetermined whereby to sufficiently and uniquely determine the laser's oscillating frequency and to force the laser to perform a stable single-mode or narrow band operation; and

(4) creating said gain region within a narrow area along the optical axis of said cavity and immediately adjacent to one of said end mirrors so as to promote single longitudinal mode operation.

11. In the method of claim 10, said formation including

(1) a first formation comprising a monochromatic polarizer means; and

(2) a second formation comprising an etalon.

12. In the method of claim 11, further comprising the steps of

(1) using a nonlinear crystal means arranged in an optimal condition including phase-matching for intracavity frequency conversion;

(2) maintaining the bandwidth of said formation to be smaller than the laser longitudinal oscillating mode interval of said cavity, and its free spectral range is larger than the FWHM of lasing bandwidth of the gain medium;

(3) building said monochromatic polarizer means up of a polarizer and said nonlinear crystal means; and

(4) selecting said laser cavity from the group including 1) regular standing-wave cavities; 2) V-shaped standing-wave cavities; and 3) L-shaped standing-wave cavities.

13. In the method of claim 12, in order to protect the laser polarization at the fundamental wavelength from being altered or affected by the amount of birefringence of said nonlinear crystal means and said laser medium means; further comprising the steps of

(1) keeping said nonlinear crystal means to have a constant effective length to produce a phase retardation to be a half integral multiple of said fundamental wavelength; and

(2) selecting said laser medium from the group including 1) nonbirefringent laser medium, and 2) birefringent laser medium having a constant effective length to produce a phase retardation to be a half integral multiple of said fundamental wavelength.

14. In the method of claim 12, further comprising the steps of

(1) maintaining a constant cavity length whereby stabilizing operation frequency;

(2) maintaining a constant temperature for said nonlinear crystal means whereby providing the best result for frequency conversion and minimizing cavity losses for the oscillating mode; and

(3) constructing a wavelength tuning form for the alignment of said etalon transmission peak to said laser oscillation frequency.

15. In the method of claim 10, further selecting a nonlinear crystal means arranged in an optimal condition including phase-matching for intracavity frequency conversion, wherein said frequency conversion includes

(1) second harmonic generation, wherein said nonlinear crystal means including KTP;

(2) resonantly enhanced second harmonic generation, wherein

A. said nonlinear crystal means including KTP;

B. said formation is a regular etalon; and

C. said cavity arrangement is configured to resonate at said second harmonic frequency by a phase compensator means or cavity distance adjustor means whereby largely enhancing the intensity of said second harmonic radiation and the conversion efficiency;

(3) third harmonic generation, wherein

said nonlinear crystal means is two nonlinear crystals positioned serially, in which the first crystal is set with type I phase-matching for doubling said fundamental radiation to produce the SHG, and the second crystal is set with type II phase-matching to mix said fundamental and second harmonic radiations so as to produce the THG;

(4) third harmonic generation with resonant harmonic generation, wherein

A. said nonlinear crystal means is two nonlinear crystals positioned serially, in which the first crystal is set with type I phase-matching for doubling said fundamental radiation to produce the SHG, and the second crystal is set with type II phase-matching to mix said fundamental and second harmonic radiations so as to produce the THG;

B. said formation is a regular etalon; and

C. said cavity arrangement is configured to resonate at said second harmonic frequency by a phase compensator means or cavity distance adjustor means whereby largely enhancing the intensity of said second harmonic radiation and the conversion efficiency;

(5) fourth harmonic generations, wherein

said nonlinear crystal means is three nonlinear crystals positioned serially, in which the first crystal is set with type I phase-matching for doubling said fundamental radiation to produce the SHG, the second crystal is set with type II phase-matching to mix said fundamental and second harmonic radiations for producing the THG, and the third crystal is set with type I phase-matching to mix said fundamental and third harmonic radiations so as to produce the FHG;

(6) fourth harmonic generation with resonant harmonic generation, wherein

A. said nonlinear crystal means is two nonlinear crystals positioned serially, in which the first crystal is used for doubling said fundamental radiation to a second harmonic radiation, and the second crystal is for doubling said second harmonic radiation to a quadrupling harmonic radiation;

B. said formation is a regular etalon; and

C. said cavity arrangement is configured to resonate at said second harmonic frequency by a phase compensator means or cavity distance adjustor means whereby largely enhancing the intensity of said second harmonic radiation and the conversion efficiency;

(7) frequency mixing, wherein

A. further selecting an input radiation, including a resonantly enhanced input; and

B. said nonlinear crystal means mixes said fundamental and said input radiations to a mixing radiation; and

(8) frequency mixing with resonant harmonic generation, wherein

A. further selecting an input radiation;

B. said nonlinear crystal means is two nonlinear crystals positioned serially, in which the first crystal is used for doubling said fundamental radiation to produce the SHG, and the second crystal mixes said second harmonic and said input radiations to a mixing radiation;

C. said formation is a regular etalon; and

said cavity arrangement is configured to resonate at said second harmonic frequency by a phase compensator means or cavity distance adjustor means whereby largely enhancing the intensity of said second harmonic radiation and the conversion efficiency.